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MANAGING THE EFFECTIVENESS OF MACHINES DURING THE ASSIGNMENT OF TASKS TO THE PRODUCTION

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Abstract: The allocation of production tasks to specific production resources is an important part of preparing the manufacturing process. The amount of profit and costs incurred depends on this division. The efficiency of production resources depends not only on the technologies used, but also on the tasks that will be carried out on them. Therefore, the management of machine efficiency includes both an evaluation (analytical and assessment undertaking, e.g. OEE) and planning activities aimed at maximizing the efficiency of machines by appropriately assigning production tasks to them.
The article presents the problem of the allocation of production of various products to various production resources, including the efficiency of the use of machines and devices, emphasizing the possibilities of undertaking optimization actions in the cost management process. A mathematical model was formulated for this issue. An algorithm solving the problem of allocation of production tasks is presented. The solution was obtained using the Octave computing environment.

Keywords: OEE, multi-station work, optimization, linear programming

1. INTRODUCTION

Machines and devices are strategic assets of every production plant. They take a direct part in the technological process, where they create added value to the products - they change the shape, physical, chemical, thermal (and other) properties of the products (by carrying out machining processes), they also affect the change in the mutual position of individual elements in the product (as part of assembly processes) (Klimecka-Tatar, and Shinde, 2019; Ingaldi and Ulewicz, 2020;). Optimization of functionality and time of uninterrupted operation of machines and devices is an important issue related to increasing the company's efficiency and its competitiveness on the market in every industry (Anand and Nandurkar, 2012; Drljača, M., 2019). In any enterprise, many machines could certainly operate more efficiently. Research shows that most machines produce only half of what they could produce, and that the total use of resources is around 30-50% (Knop, 2018). Cost reduction by the proverbial 1 PLN brings the company greater profit than an increase in sales by the same amount. By optimizing the use of production resources, manufacturing companies increase the profits of each PLN invested (Ulewicz et al., 2019). The concept of the effectiveness of the use of machinery and equipment is becoming increasingly important as one of the variables making up the company's success. Efficiency is a key element of the company's development, serving self-fulfillment and its survival (Zimon, 2015). One of the methods of measuring the effectiveness of production equipment is the indicator of the Overall Equipment Effectiveness, abbreviated OEE (Krynke et al., 2014). This is the basic measure used in the concept of comprehensive maintenance of TPM machines (Borkowski et al., 2006). The efficiency of production resources depends not only on the technologies used, but also on the tasks that will be carried out on them. Therefore, the management of machine efficiency includes both an evaluation (analytical and assessment undertaking, e.g. OEE) and planning activities aimed at maximizing the efficiency of machines by appropriately assigning production tasks to them (Krynke et al., 2018).

The aim of the article is to analyze the allocation of production of various products to various production resources, taking into account the effectiveness of the use of machines and devices, emphasizing the possibilities of undertaking optimization actions in the cost management process.

2. ASSESSMENT OF THE EFFICIENCY OF USING MACHINES AND EQUIPMENT

Progress in the TPM concept is mainly measured by calculating the Overall Equipment Effectiveness OEE, which is an indicator that combines work efficiency, machine reliability and the quality of the manufacturing process. The OEE indicator is a useful tool illustrating to what extent machines and devices work effectively, i.e. how effectively they are used. It is calculated according to the following formula (Borkowski et al., 2006):

$$OEE = A \cdot P \cdot Q \cdot 100 \ [\%] \tag{1}$$

gdzie:
A – Availability factor,
P – Performance factor,
Q – Quality factor.

The OEE indicator has become a standard in measuring machine performance widely described and used by many companies. By analyzing the obtained OEE values for individual machines and devices, you can find out what is the actual level of deviations of the plant's OEE values from world standards, and what machines and devices are called "Bottleneck" in the plant tested.

The world standard for the OEE (World Class) indicator is over 85%. At present, it is assumed that if an analysis of the OEE indicator obtained a result above 85%, it confirms the fact of choosing the right strategy for the operation of machines and devices of the analyzed plant. Each result below global standards shows the location and directions of necessary corrective actions for the machines and devices of the audited plant in operation. Currently, many production plants are systematically registering OEE indicators, which improve their production efficiency and strengthen their high market position. Thanks to their simple structure, OEE indicators are understandable for all staff and thus their unique impact on the shaping of the plant's operation is confirmed, regardless of the type of industry (Jagusiak-Kocik et al., 2016; Mielczarek and Krynke, 2018).

3. RESEARCH PROBLEM

Production tasks segmentation is an important part of a production process. It is connected with the size of the profit and costs. Production tasks should be allocated in order for the profit made by the production system to be maximized while, at the same time, the costs are maximized (Bard and Nananukul, 2010; Dehghanbaghi and Sajadieh, 2017; Lukač et al., 2008; Krynke, 2020).

In this article a problem of dividing 5 production tasks between 4 workstations was presented in such a way that the cost of the realization was smallest. The following research problem was considered.

There are 4 machines whose available standard hours of work were given in Table 1. With the help of these machines the production program of five products should be realized. Manufacturing cost (1 hour) of the machine j for the one product i are shown in Table 2. The production of every product can be divided in randomly between the machines. The hourly productivity of machines depends on which product is produced on a given machine. Individual value was given in Table 1. The production tasks should be allocated to machines in such a way so that the total cost of the realization of the production program is minimal.

The machines are characterized by varying degrees of modernity and technologies used. Therefore, the production of a given product on different machines is varied. It has other indicators of efficiency and quality. Therefore, in the allocation of tasks to individual machines, individual factors should be taken into account that make up the value of the OEE indicator. Data on availability, performance and quality ratios are presented in Tables 3-5.

Table 1
Productivity of individual machines depending on products

Products	Machines [piece/hour}				Planning for production [piece/month]
	M1	M2	M3	M4	
P1	200	200	500	300	20000
P2	700	250	300	200	25000
P3	450	300	400	400	18000
P4	400	300	200	300	15000
P5	100	400	600	200	20000
Available standard hours of work [hour/month]	40	88	64	96	

Table 2
Cost per piece of the machine *j* for the product *i*

Products	Material cost [PLN]	Machines [PLN/hour]			
		M1	M2	M3	M4
P1	1.5	10	25	10	40
P2	1.0	10	30	35	25
P3	2.0	10	30	10	10
P4	1.5	30	15	15	25
P5	2.0	25	30	50	10

Table 3
Availability factor (A)

Products	Machines			
	M1	M2	M3	M4
P1	0.92	0.91	0.88	0.87
P2	0.87	0.86	0.89	0.85
P3	0.92	0.88	0.88	0.89
P4	0.93	0.86	0.94	0.93
P5	0.93	0.89	0.94	0.88

Table 4
Performance factor (P)

Products	Machines			
	M1	M2	M3	M4
P1	0.76	0.89	0.89	0.88
P2	0.88	0.89	0.92	0.86
P3	0.89	0.92	0.94	0.93
P4	0.94	0.91	0.93	0.95
P5	0.93	0.94	0.91	0.85

Table 5
Quality factor (Q)

Products	Machines			
	M1	M2	M3	M4
P1	0.99	0.97	0.95	0.98
P2	0.96	0.98	0.97	0.99
P3	0.93	0.99	0.96	0.98
P4	0.92	0.98	0.99	0.98
P5	0.94	0.98	0.98	0.97

4. COMPUTING ENVIRONMENT AND OPTIMIZATION ALGORITHM

Linear programming was used to solve the above problem. The linear programming is the most often applied model of the optimization on account of the existence of finding efficient algorithms of optimal solution. The intuitiveness of linear relations appearing in the mathematical model (Ficken 2015).

The simplex method was used in the linear programming algorithm. This method allows to find solutions in short time and is applied in many popular solve e.g. Matlab or Octave (Maros, 2003).

In order to describe this situation with mathematical model a way to characterise the allotted tasks with the help of numbers should be found. The first parameter is cost connected with the realization of individual products, and the second parameter is available standard hours of work. It is possible to describe cost per piece of the machine *j* and the working time. An assessment of the effectiveness of work is a more difficult problem. In this example, work efficiency is expressed by the performance of individual machines including the OEE (Overall Equipment Effectiveness) indicator. In the case of products which were already made on a given machine, determining their productivity is straight and quite accurate. However, in the case of a new product their preliminary estimation, and later correction will be necessary (Krynke et al., 2019).

The monthly total cost of the realization of the production program are described as:

$$F(x_{ij}) = \sum_{i=1}^{5}\sum_{j=1}^{4}\left(Cprod_{ij} \cdot x_{ij} + w_{ij} \cdot A_{ij} \cdot P_{ij} \cdot (1 - Q_{ij}) \cdot Cmat_i \cdot x_{ij}\right) \rightarrow min \quad (2)$$

where: x_{ij} – number of machine hours *j* for the product *i*, (value sought)

$Cprod_{ij}$ – cost for one working hours of the machine *j* for product *i* (Table 2),

w_{ij} – productivity of machines - number of work units (1 hour) for machine *j* and product *i* assuming WW = 100% (Table 1),

A_{ij} – availability – percentage of scheduled time that the operation is available to operate (Table 3),

P_{ij} – performance – speed at which of machines runs as a percentage of its designed speed (Table 4),

Q_{ij} – quality – good units produced as a percentage of the total units started (Table 5),

$Cmat_i$ – raw material costs for products *i* (Table 2).

It is a function that should be minimized. At the same time, the available standard hours of work:

$$\begin{aligned} \sum_{i=1}^{5} x_{i1} &\le 40 \\ \sum_{i=1}^{5} x_{i2} &\le 88 \\ \sum_{i=1}^{5} x_{i3} &\le 64 \\ \sum_{i=1}^{5} x_{i4} &\le 96 \end{aligned} \quad (3)$$

and requirement concerning production order – limitations of work units (size of the batch):

$$\begin{aligned} \sum_{j=1}^{4} x_{1j} \cdot w_{1j} \cdot A_{1j} \cdot P_{1j} \cdot Q_{1j} &= 20\,000 \\ \sum_{j=1}^{4} x_{2j} \cdot w_{2j} \cdot A_{2j} \cdot P_{2j} \cdot Q_{2j} &= 25\,000 \\ \sum_{j=1}^{4} x_{3j} \cdot w_{3j} \cdot A_{3j} \cdot P_{3j} \cdot Q_{3j} &= 18\,000 \\ \sum_{j=1}^{4} x_{4j} \cdot w_{4j} \cdot A_{4j} \cdot P_{4j} \cdot Q_{4j} &= 15\,000 \\ \sum_{j=1}^{4} x_{5j} \cdot w_{5j} \cdot A_{5j} \cdot P_{5j} \cdot Q_{5j} &= 20\,000 \end{aligned} \quad (4)$$

Defined task is possible to be solved in the environment Octave. Octave is a free programme for numerical calculations (mathematical and engineering calculations). This language is intuitive and friendly (for a mathematician) (Nagar, 2018). With basic functionality in Octave there are operations on matrices and number of numerical methods solving linear and non-linear problems. Octave is software featuring a high-level programming language, primarily intended for numerical computations. Octave helps in solving linear and nonlinear problems numerically, and it is used for performing other numerical experiments with the use of a language that is mostly compatible with MATLAB.

The issue of of planning the production of products on individual machines was solved using the GLPK command. The GNU Linear Programming Kit (GLPK) is a software package intended for solving large-scale linear programming (LP), mixed integer programming (MIP), and other related problems (Piechna, 2012).
GLPK uses the revised simplex method and the primal-dual interior point method for non-integer problems and the branch-and-bound algorithm together with Gomory's mixed integer cuts for (mixed) integer problems.

5. ANALYSIS OF THE RESULTS

After doing calculations, the optimal values of working hours of individual machines was obtained. In Fig. 1 machine time fund against the background of available standard hours of work was presented.
The calculations take into account the minimization of total costs (production costs and cost of defective products). In addition, the restrictions on the available standard operating hours for individual machines were met, and the value of the OEE indicator was taken into account in accordance with tables 3-5. For a planned production process, the production of the product P1 will be the most effective only on the machine M3, the production of the product P2 on the machine M1, M2 and M3, the production of the product P3 only on the machine M4, the production of the product P4 on the machine M2 and M4 and the production of product P5 on the machine M2 with a small share of the M4 machine.

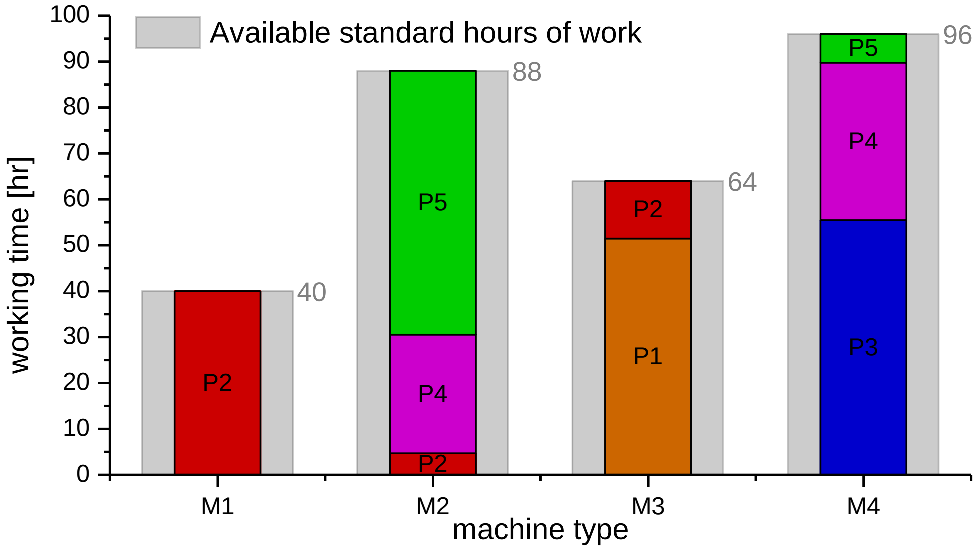

Fig. 1. Optimal assignment tasks to individual machines against the background of available standard hours of work

Figure 2 shows the use of machines received for various optimization criteria. The operating time of the machines was compared for three situations, where the production costs were minimized each time. In the first case, the OEE factor = 100% and the limitation resulting from the available working hours for each machine were assumed. In the second case, the OEE coefficient is consistent with the data given in Tables 3-5, while in the third case the machine working time is unlimited. The machine working time fund, which results from the available standard working hours, is fully utilized for the second case of optimization. In the third case, the available working hours on M1 and M4 machines are exceeded, but it has a positive effect on lower production costs (Fig. 3).

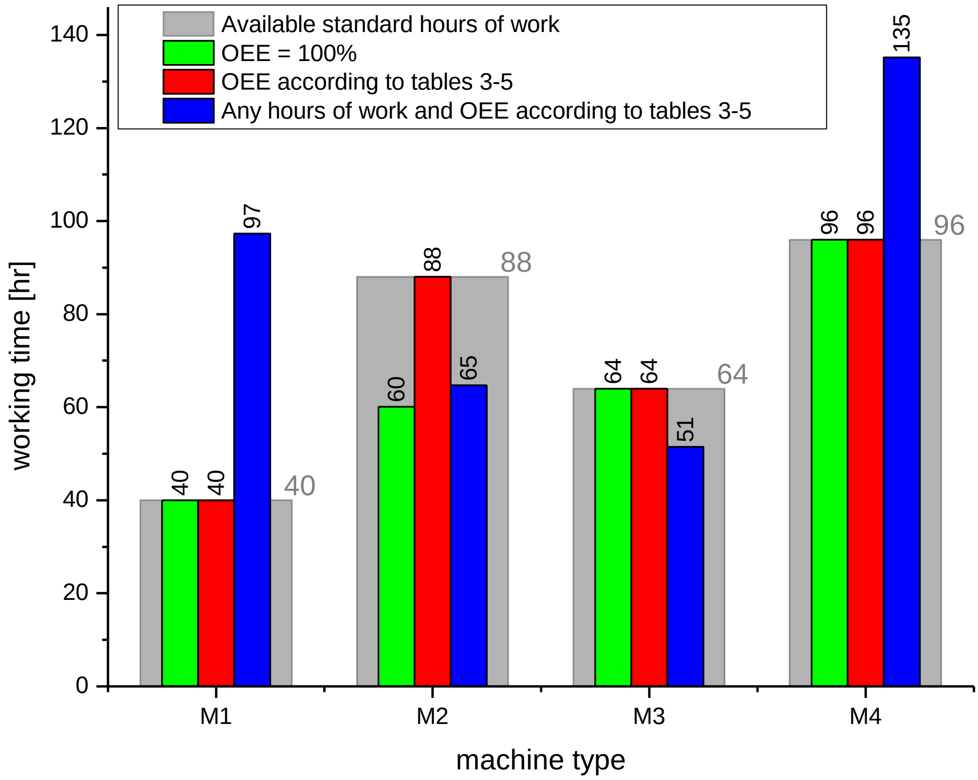

Fig. 2. Machine working time for various optimization criteria

Figure 3 presents a chart comparing the total cost of implementing the procurement program for six optimization criteria. The first 3 cases relate to the optimal solution when the costs are minimized. For comparison, another 3 cases show situations where production costs have been maximized.

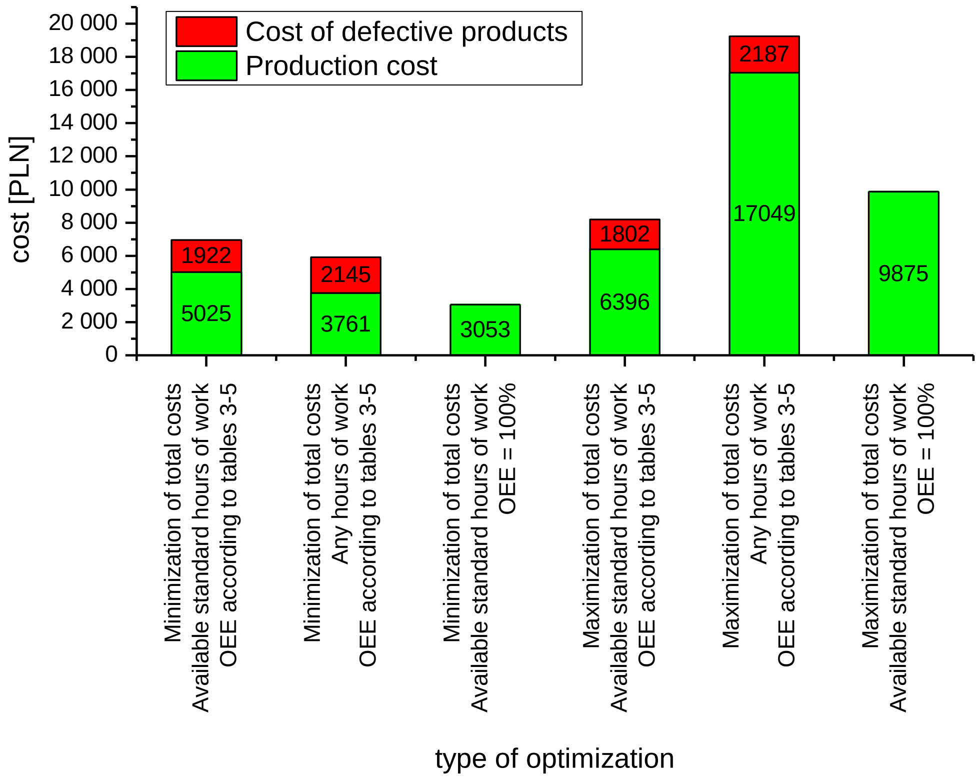

Fig. 3. Total cost of the realization of the production program for various optimization criteria

The presented comparison it is clear that improper allocation of production tasks can dramatically increase production costs, in this case several times. It is worth noting also that the total costs depend not only on the same production costs but also the costs of defective products. Therefore, when estimating the cost of production, it is important to also take into account the quality factor, which is also a component of OEE factor.

6. CONCLUSION

The article presents the problem of the allocation of production of various products to various production resources, including the efficiency of the use of machines and devices, emphasizing the possibilities of undertaking optimization actions in the cost management process.

The presented analyzes prove that in addition to increasing the efficiency of individual machines and devices, it is also very important to optimally allocate tasks to specific production resources. Such optimization should be carried out globally, i.e. including all tasks and all production resources, including their availability, performance and quality. The presented example shows that production costs can increase even several times with extremely improper use of production resources.

The management of the machine working time fund is also important when planning production. Typically, the available machine working hours result from the planned production schedule. However, for comparison, it is worth conducting a simulation in which any number of hours of machine operation is assumed. The presented example shows that such a change causes an additional reduction in production costs, in the example given it is almost 15% compared to the standard available working hours.

Linear programming is one of the simplest ways to perform optimization. It helps solve some very complex optimization problems by making a few simplifying assumptions. It is possible to use the linear programming for the minimization of production costs as well as for the maximization of profits.

The presented example can, by analogy, be widened to a large number of machines and tasks as well as months.

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